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Plan for Establishing 700 KW Operations

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MI Department

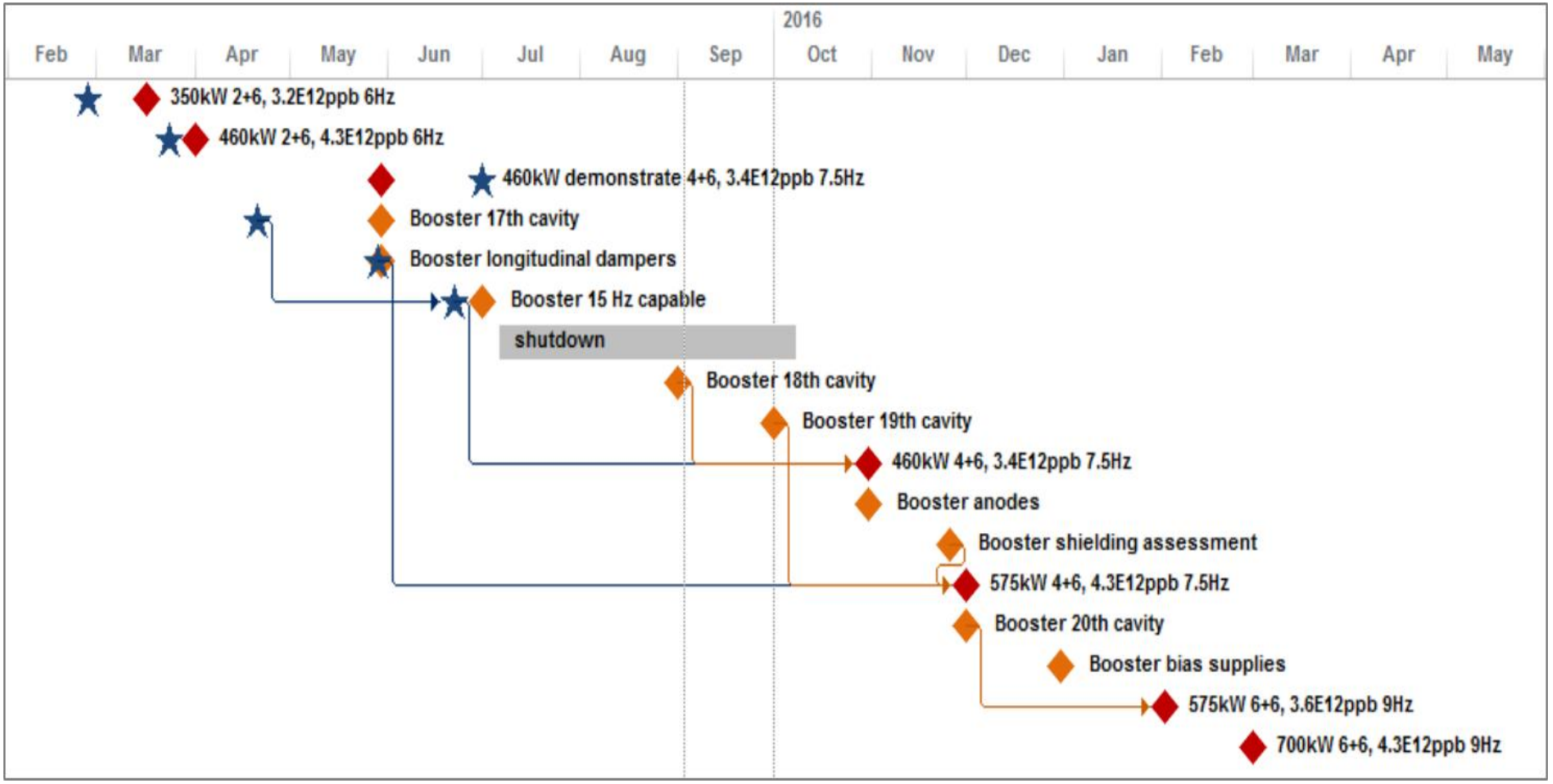
DOE 700KW Follow-up Review

11 September 2015

Introduction

- We have formulated a plan with precise timeline and milestones, to establish 700 KW operations.
- The plan includes all the hardware and operational prerequisites needed to achieve the milestones from both the MI and the Proton Source Departments.
- We are having regular and frequent communications with the Proton Source Department to ensure that the requirements from the Proton source are well understood and are on time.
- This plan is a living document updated each time a milestone is achieved or delayed with reporting at the Proton PMG.

Schedule for milestones to reach 700 KW



Booster beam parameters required for Recycler SS

Parameter	Value
Transverse Emittance	15 pi mm-mr
Long. Emittance	0.12 eV-sec
Δp	±7.5 MeV

- **Currently the beam from Booster meets the requirements**

Roadmap to 700 KW* (FY2015)

- *Switch to 2+6 Operation-March. 2015 (same power 350 KW)*
  - Main Injector Department
    - Optimize slip stacking in RR
    - Commission MI collimators

DONE

  - Proton Source Department
    - Reliable 6 Hz operation with 3.2E12ppb and proper dp/p
- *Provide 460 KW with 2+6 operation-March 2015*
  - Main Injector Department
    - Minimize losses

DONE

  - Proton Source Department
    - Reliable 6 Hz operation with 4.3E12ppb and proper dp/p
    - At least 17 RF stations operational

NuMI only operation

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FY2015 cont.

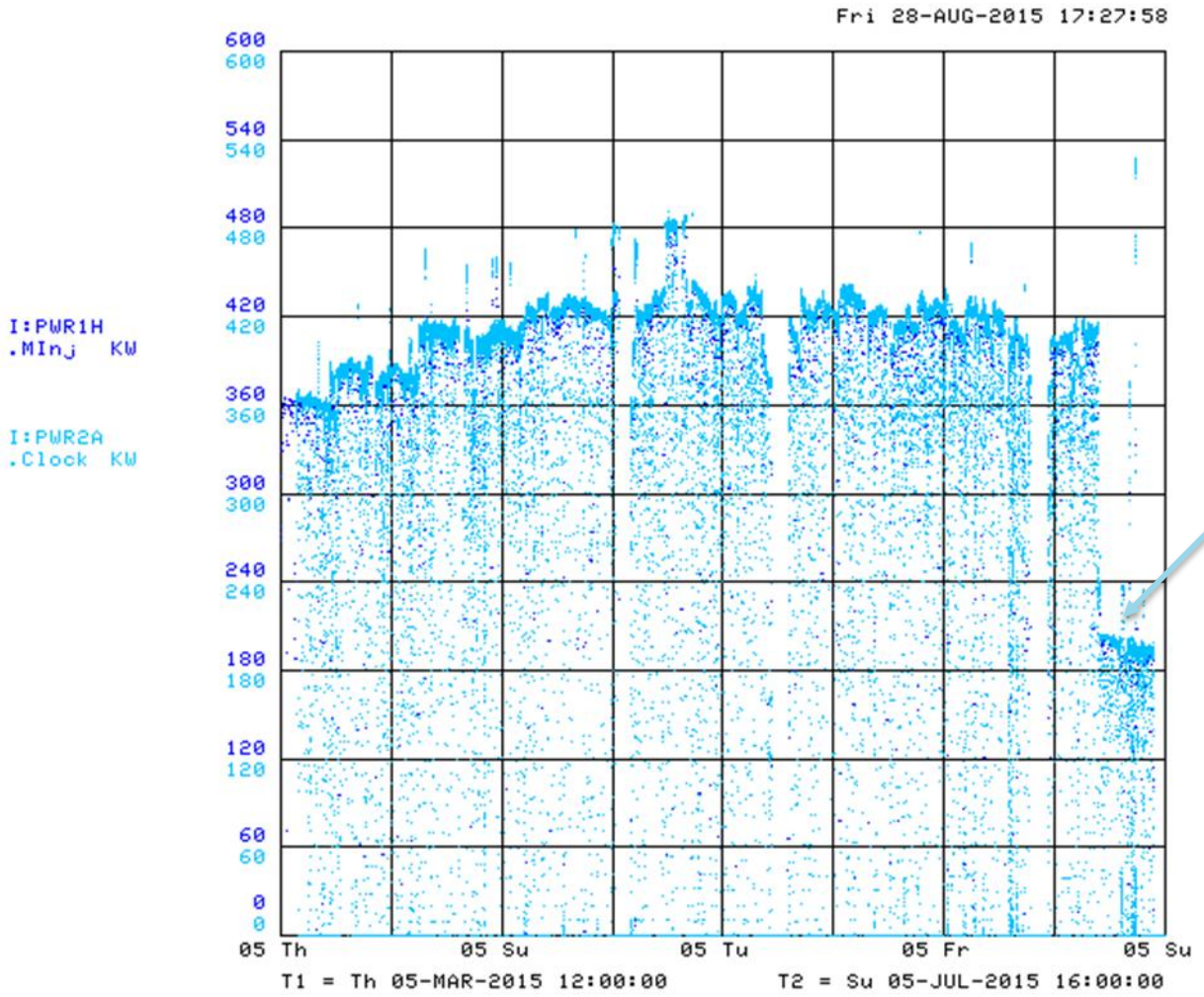
- *Demonstrate 4+6 operation by achieving 460 KW operation for at least one hour.-May 2015*
  - Main Injector Department
    - Establish 4+6 operation with 3.4E12 ppb and good efficiency.
    - Work on reducing Recycler losses.
  - Proton Source Department
    - 7.5 Hz operation with 3.4E12ppb and proper dp/p
      - 17 RF stations capable of 15 Hz operation

Achieved on July 1st 2015 (*521KW for 1hr!*)
Delayed because of Booster RF cavity failures

Current high power operation (2+6)

- On March 5th we switched to 2+6 operation, delivering ~420 KW of beam power.
  - 483 KW new MI Beam Power record (running without SY120)
  - This has been our standard operating mode till the summer shutdown.
- **We have achieved our official goal of delivering 400KW for at least one week of at least 100 hours during this year.**

2+6 operation Beam Power



Power reduction because of NuMI horn problems.

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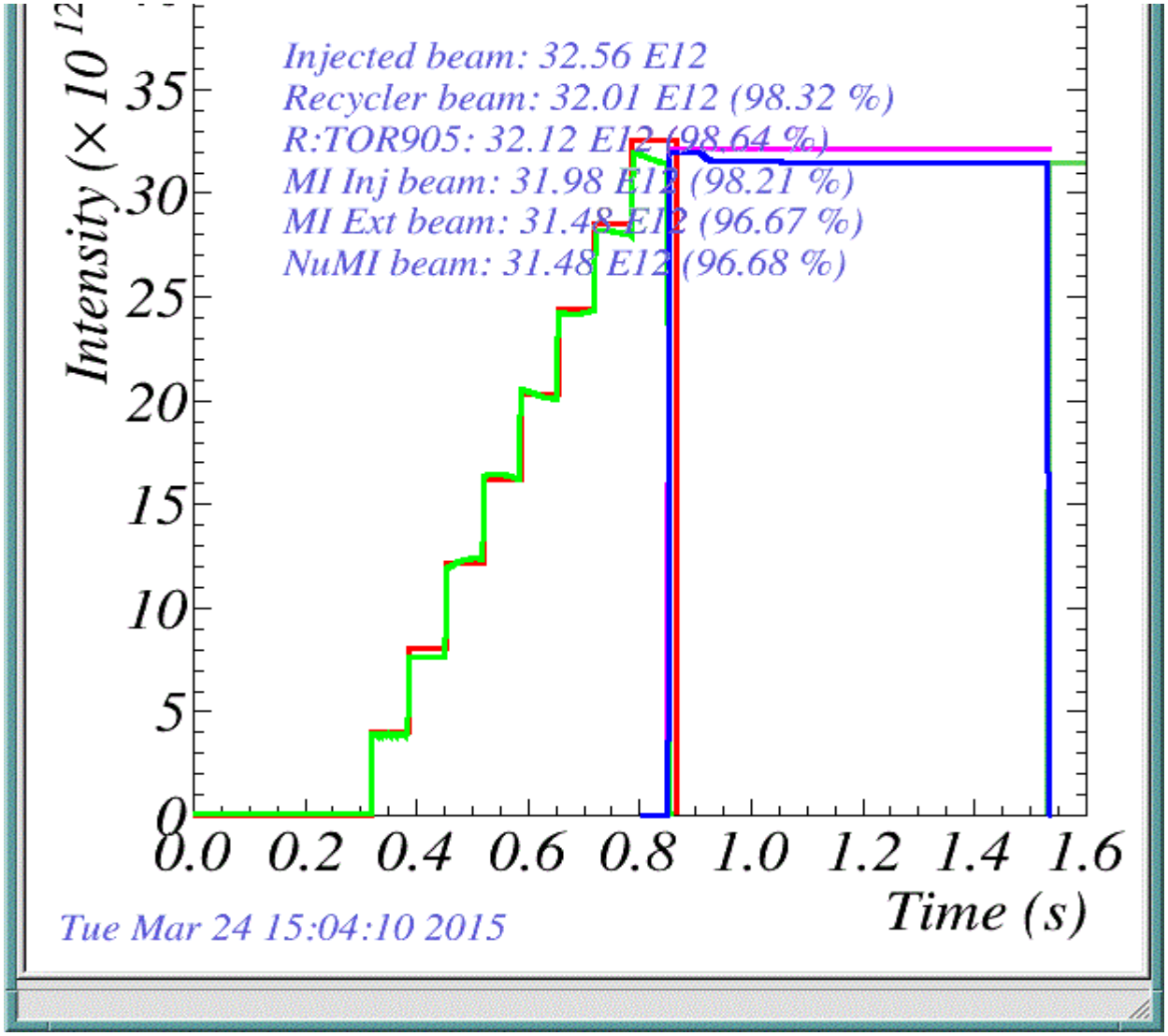
Machine efficiencies (2+6)



96.7% Overall Efficiency

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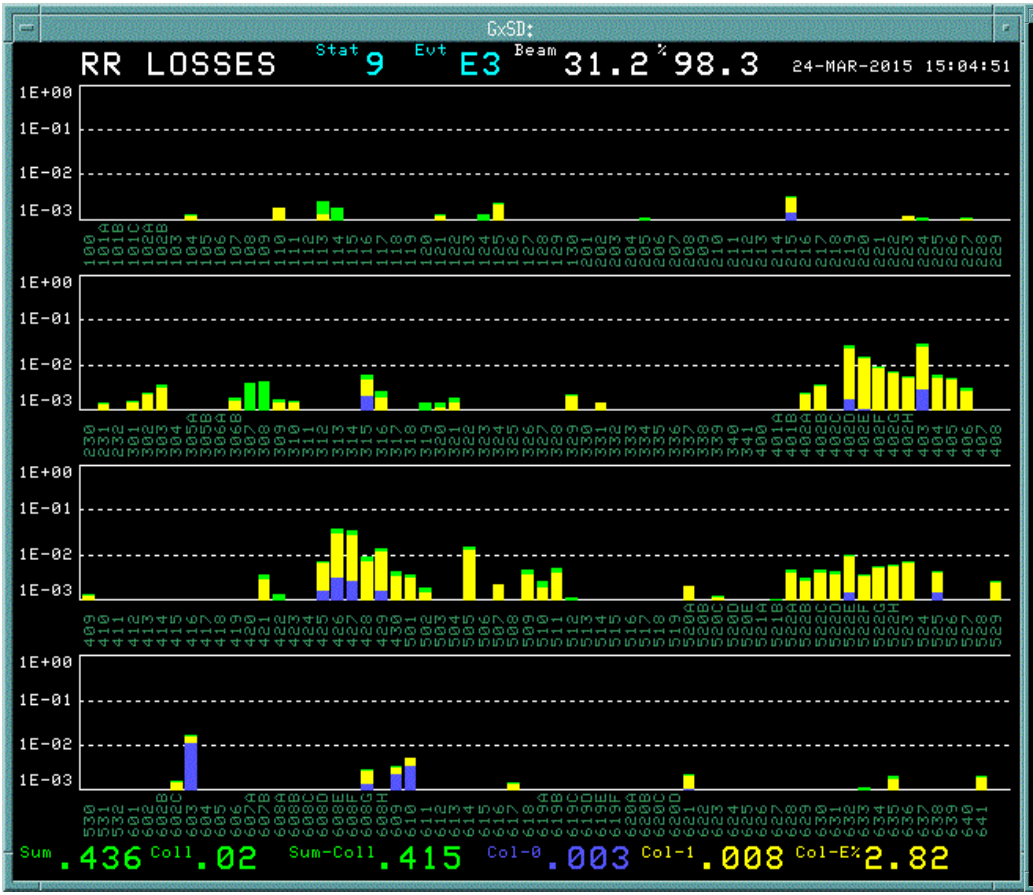
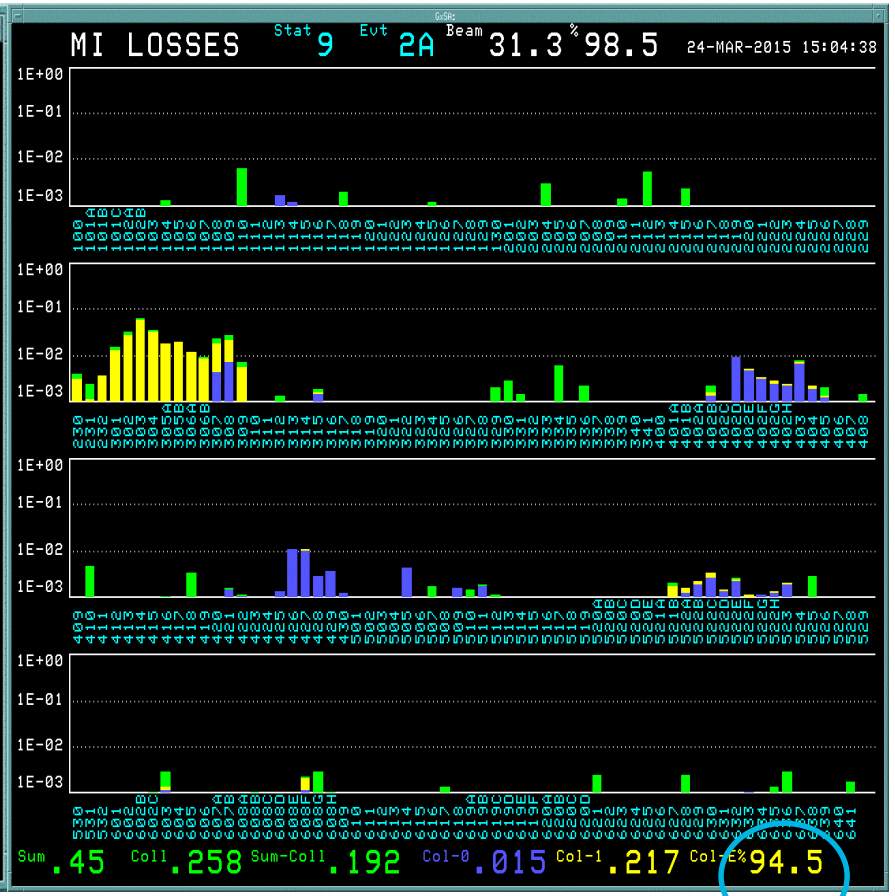
RR and MI losses (2+6)





Collimation efficiency

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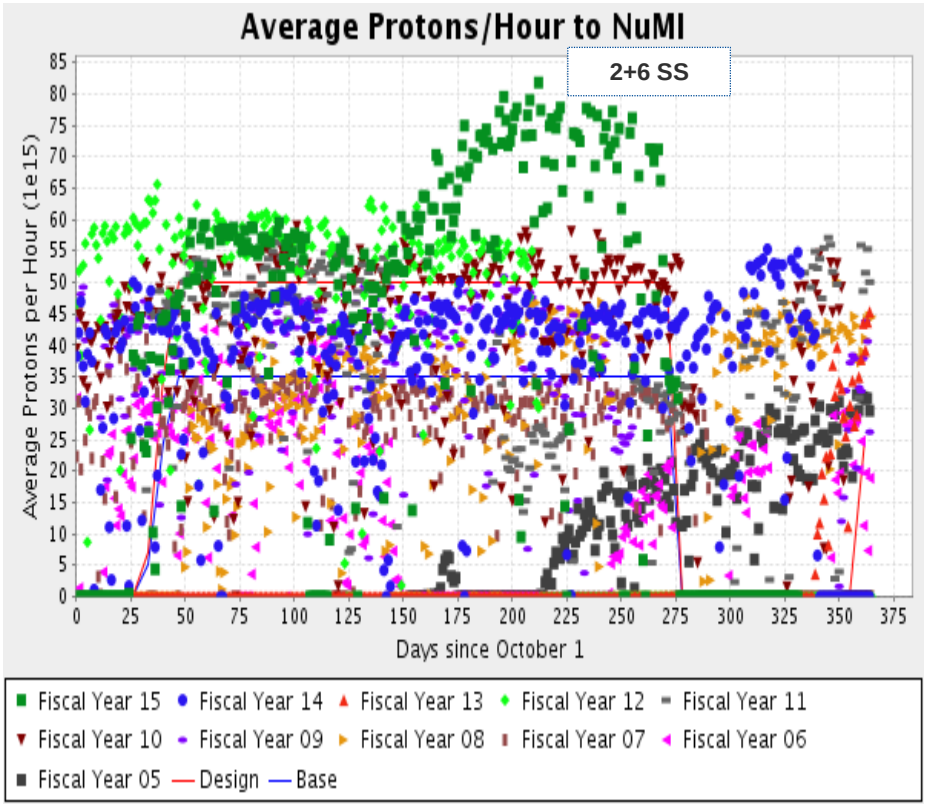
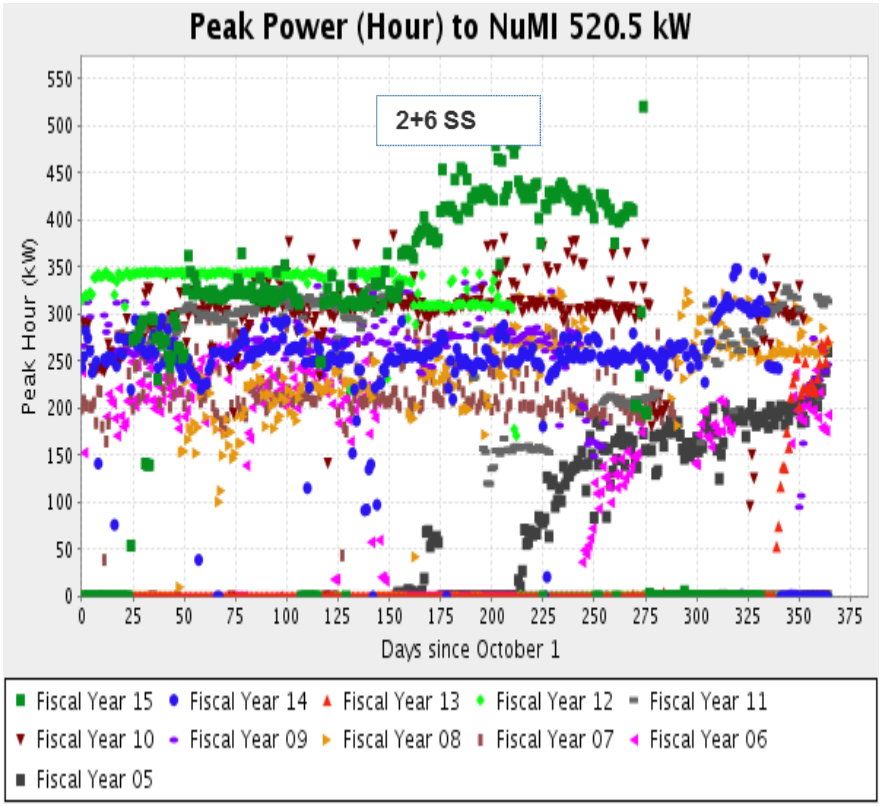
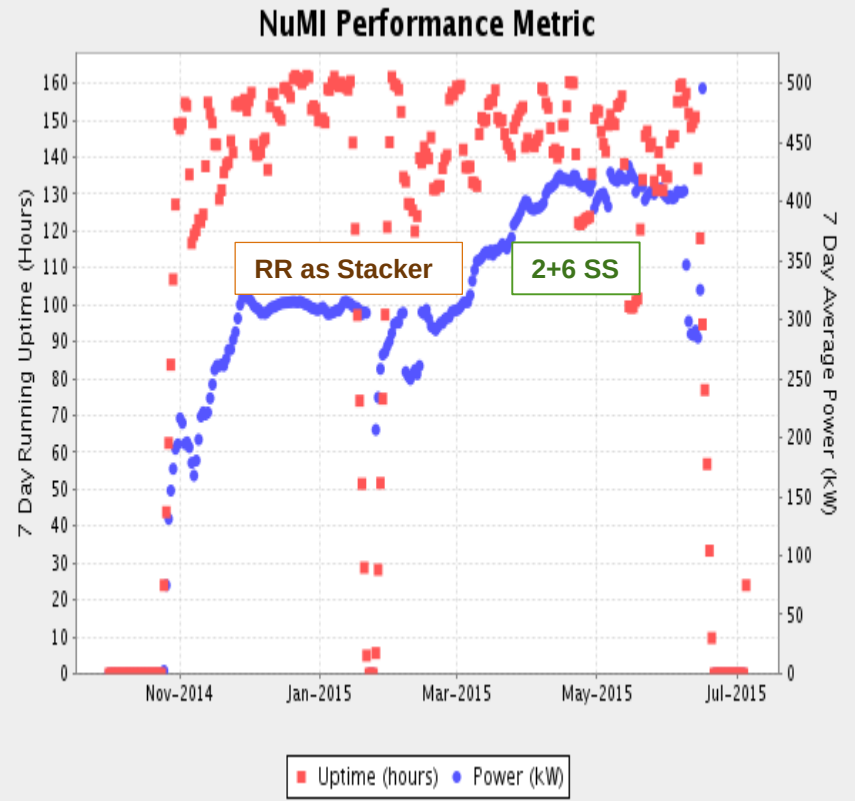
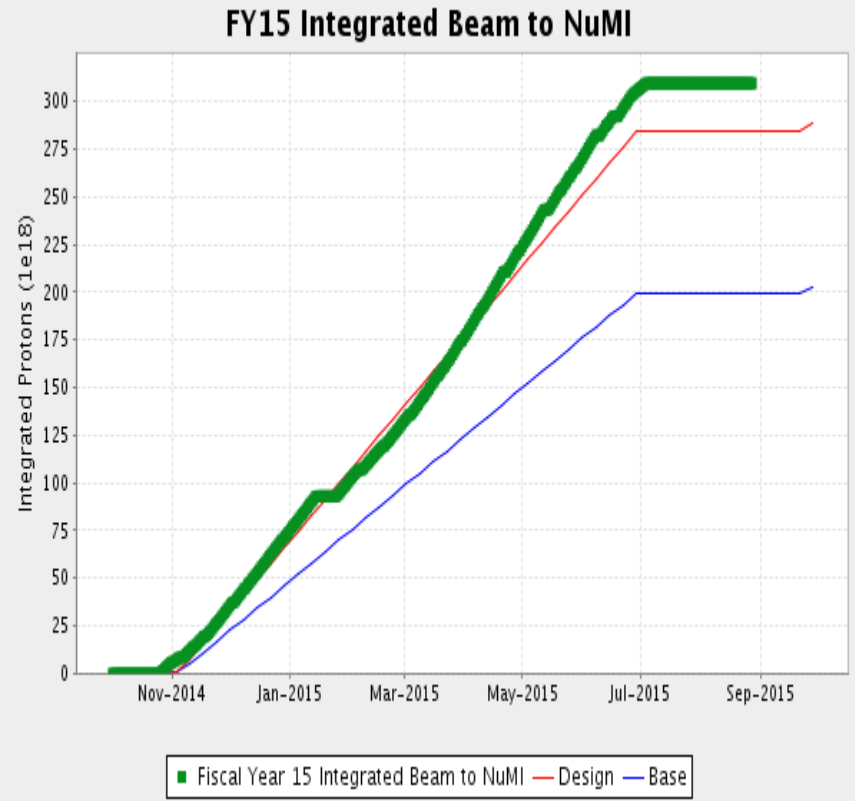
Protons per Hour and Peak power to NuMI





FY15 NuMI Performance

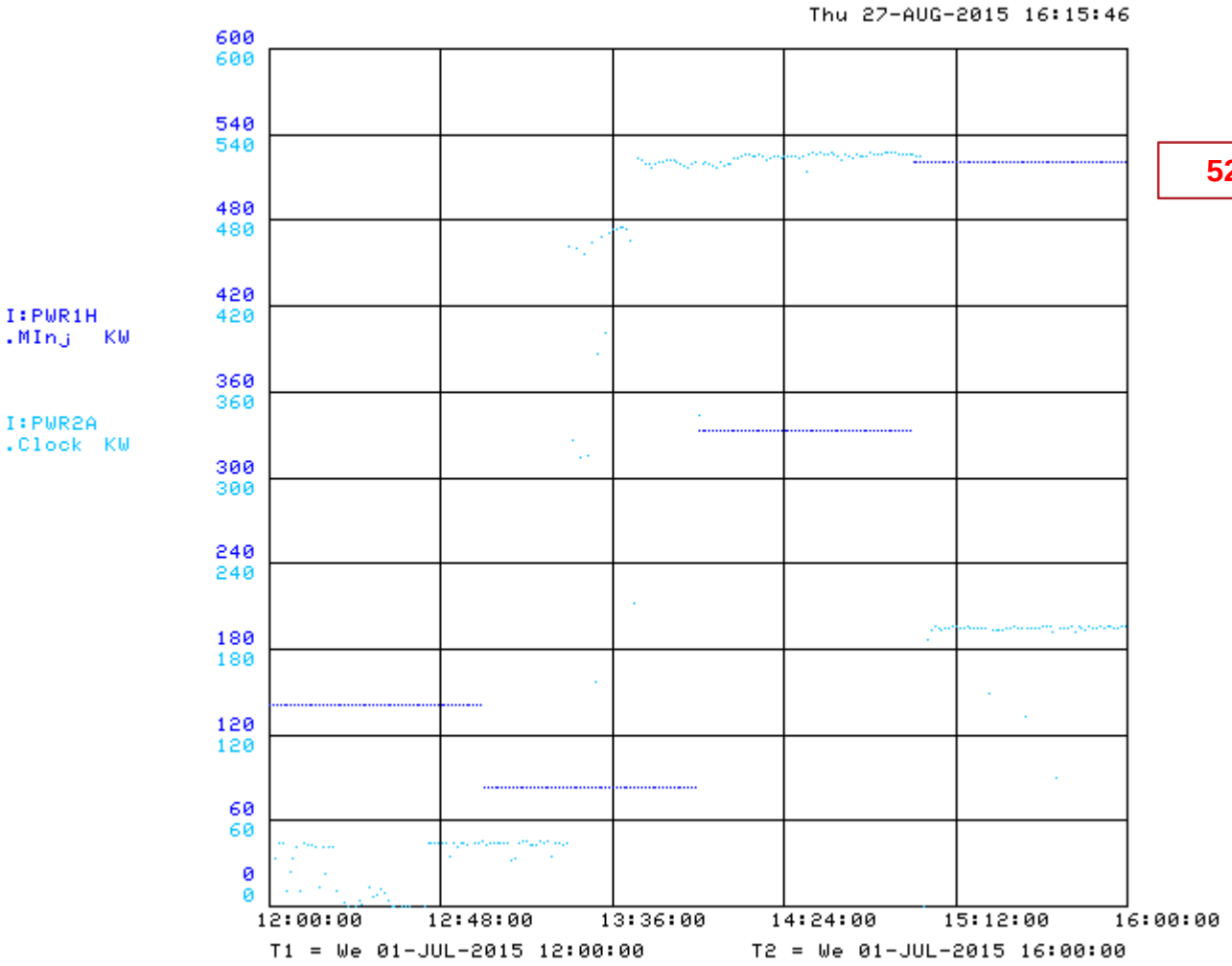




4+6 Operation

- On July 1st 2015 we switched to 4+6 operation for about two hours.
- We were able to achieve 521 KW beam power for 1 hour.
  - The injected beam intensity was 3.9E12p/batch.
  - Large beam losses but with only minimal beam tuning.

4+6 BEAM POWER



521 KW

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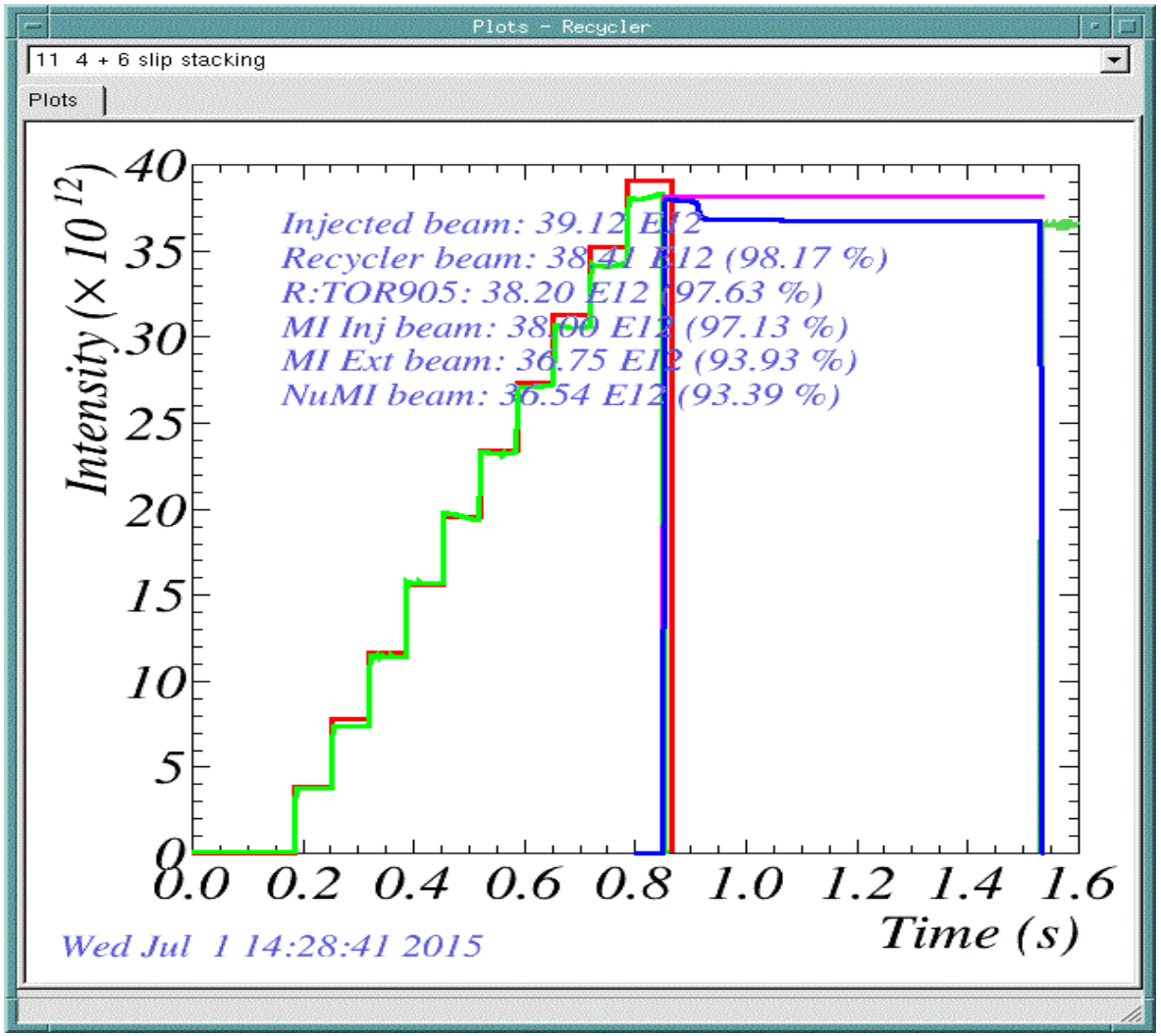
Machine efficiencies (4+6)



93.4% Overall Efficiency

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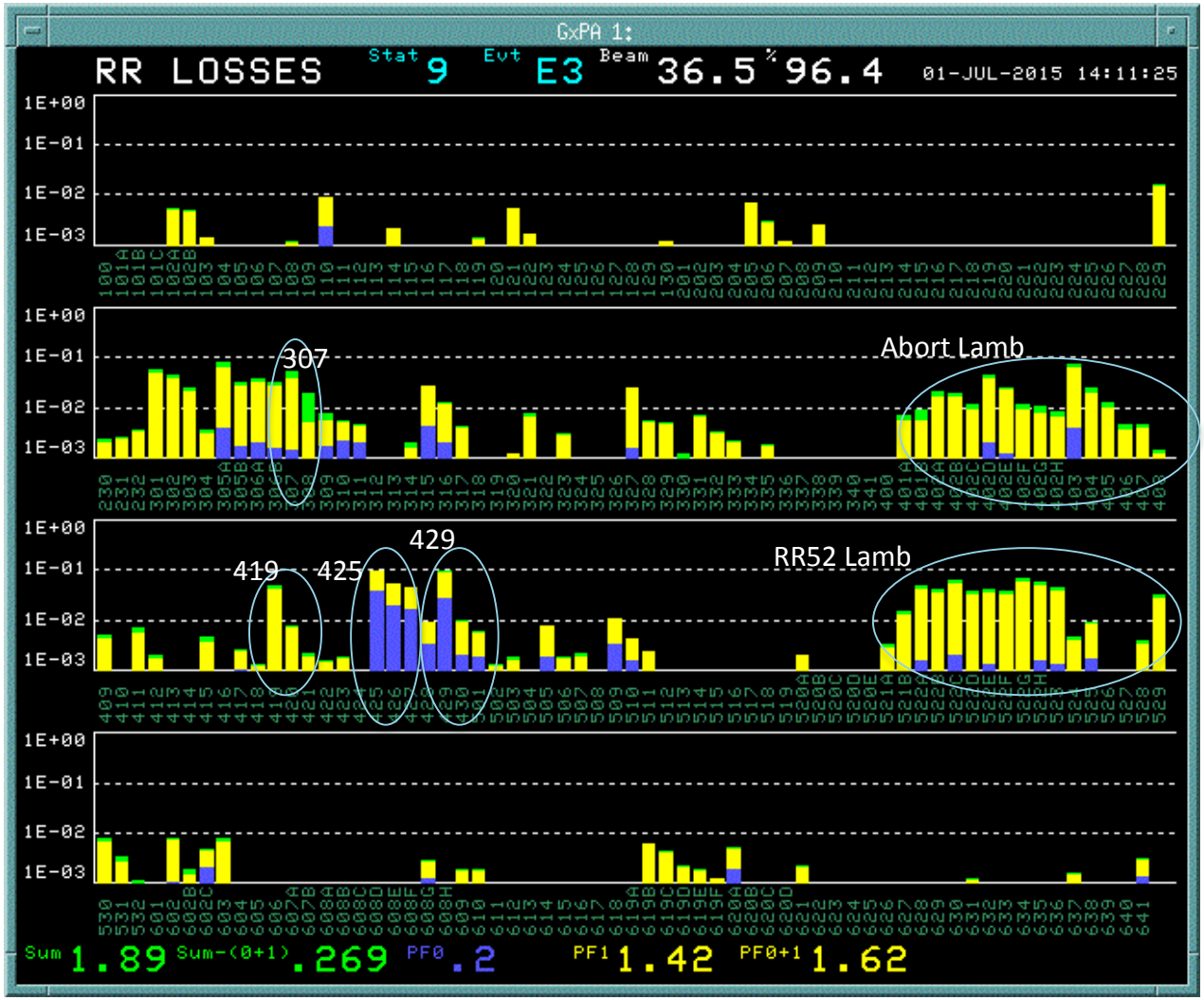
Recycler losses (4+6)



Recycler beam pipe at 307,419,425 and 429 is being replaced during the shutdown.

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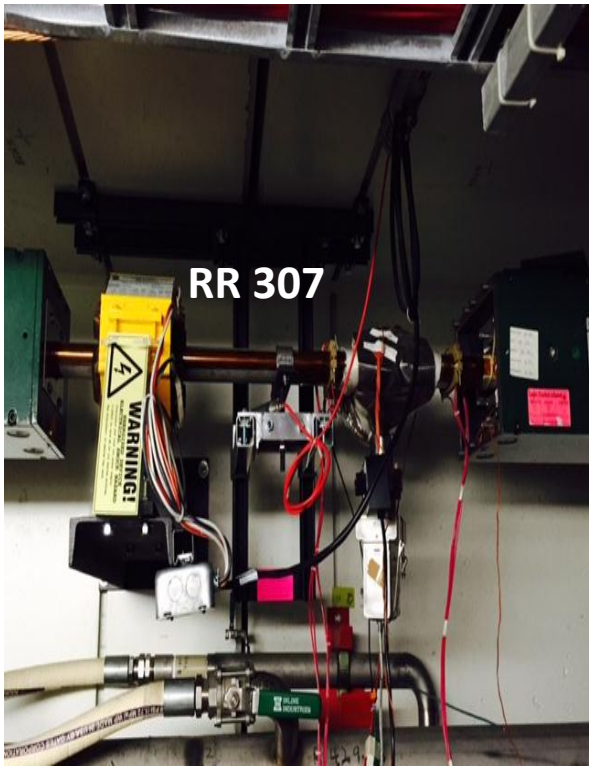
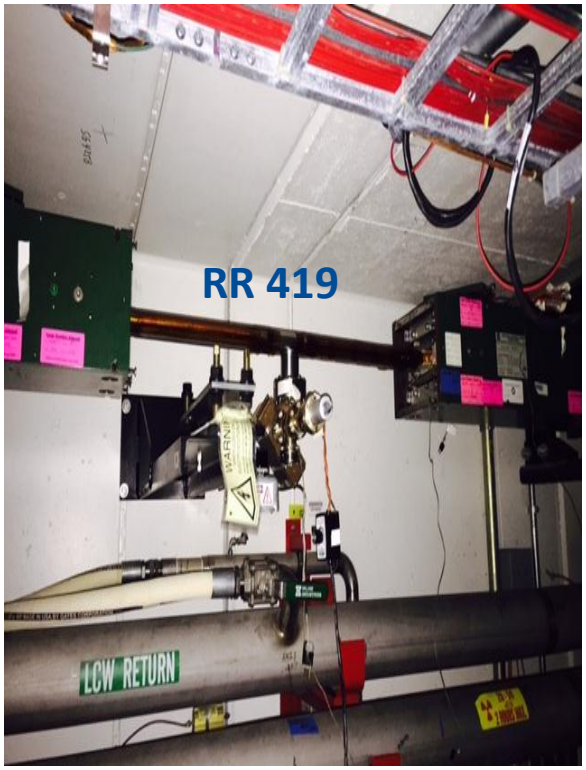
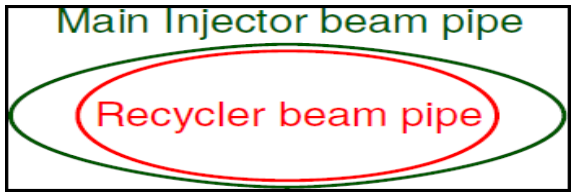
Replaced RR beam pipes





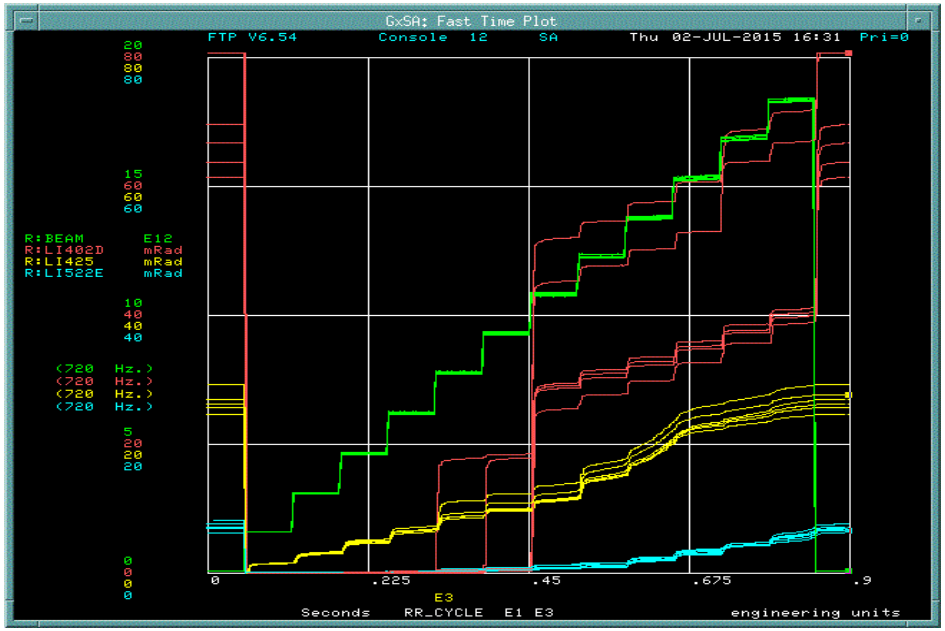


- Recycler beam pipe in the above locations was found not to be straight with extra bad welds.
- We are replacing the beam pipe at 429 this week.

Picture of the removed RR pipe at 425

6+6 operation

- On July 2nd 2015 we established for the first time 6+6 slip stacking operation and sent beam to the NuMI target for about 2 hours.
  - Low power operation ~280KW
  - Mostly done to help Booster run 15 Hz with beam.



6+6 Recycler Beam

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FY2016(1)

- Switch to 4+6 operation with 460 KW-October 2016*
  - Main Injector Department
    - Commission 4+6 operation with 3.4E12ppb and 95% efficiency.
  - Proton Source Department
    - Reliable 7.5 Hz operation with 3.4E12ppb and proper dp/p.
      - 18 Re-furbished RF stations installed (Reliability and Efficiency)
      - East and West Anode supplies completed (Reliability; Required for adding more stations)

*Assumes shutdown ends on October 4th

FY16(2)

- Achieve 575 KW with 4+6 operation-November 2016
  - Main Injector Department
    - Commission 4+6 operation with 4.3E12ppb and 95% efficiency
  - Proton Source Department
    - Reliable 7.5 Hz operation with 4.3 E12 ppb
      - 19 Re-furbished Booster RF stations installed(increased reliability and efficiency)
      - Booster longitudinal dampers operational(required for damping of coupled bunch instabilities)

FY16(3)

- Switch to 6+6 operation (same power 575 KW)-Jan . 2016
  - Main Injector Department
    - Commission 6+6 operation with 3.6E12 ppb and 95% efficiency
  - Proton Source Department
    - Reliable 9 Hz operation
      - 20 re-furbished RF stations installed (Reliability and increased efficiency)
    - Provide 3.6E12 ppb with the proper longitudinal emittance and dp/p.

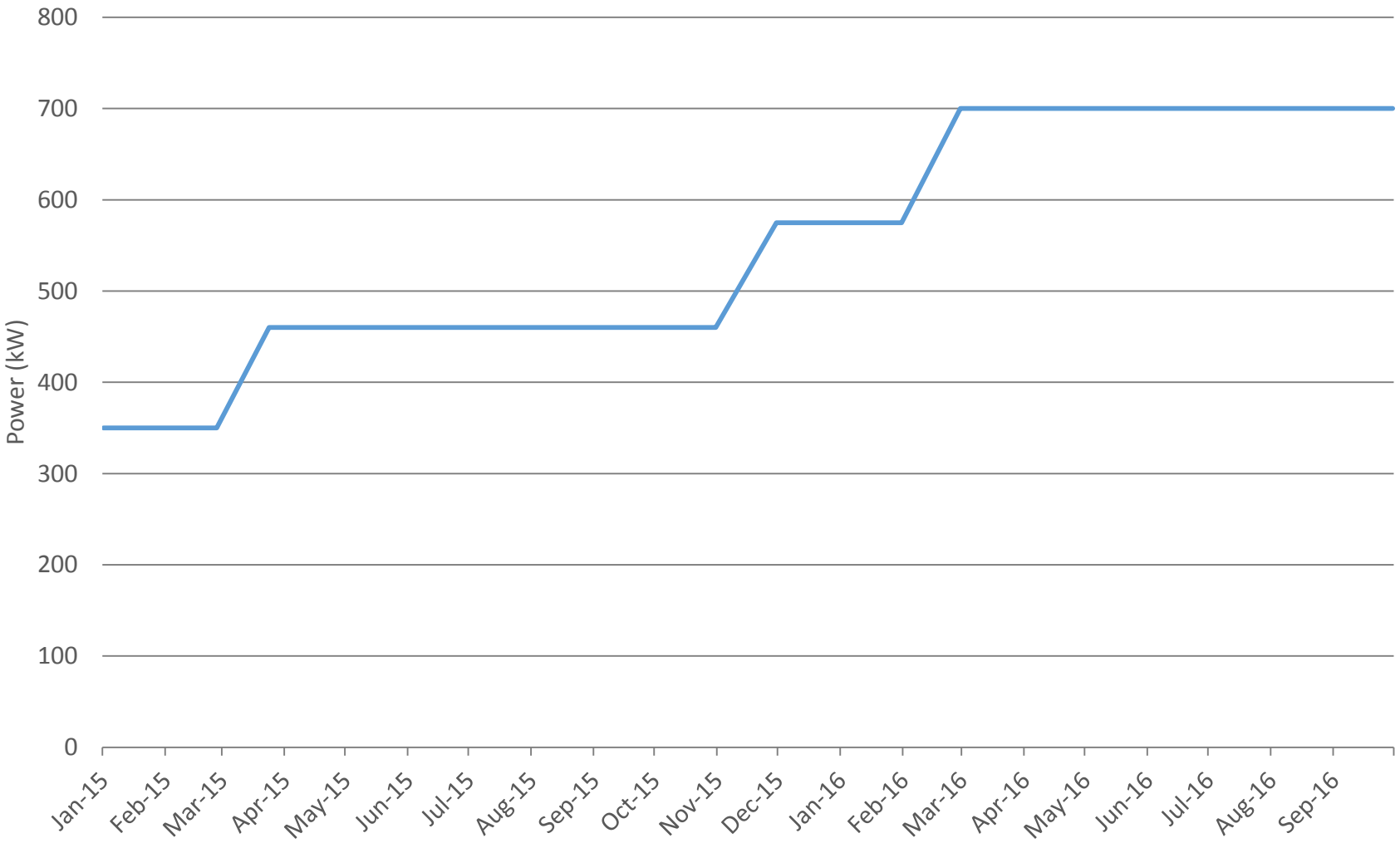
FY16 (4)

- Achieve 700 KW with 6+6 operation-Feb. 2016*
  - Main Injector Department
    - Commission 6+6 operation with 4.3E12ppb and 95% efficiency
  - Proton Source Department
    - Reliable 9 Hz operation
    - Provide 4.3E12 ppb with the proper longitudinal emittance and dp/p

*Recycler collimators may be required before we can run reliably at 700KW

We are working on a Recycler collimator design. Plan to install a primary collimator and at least a couple of secondary collimators next shutdown.

Beam Power vs Time



Conclusions

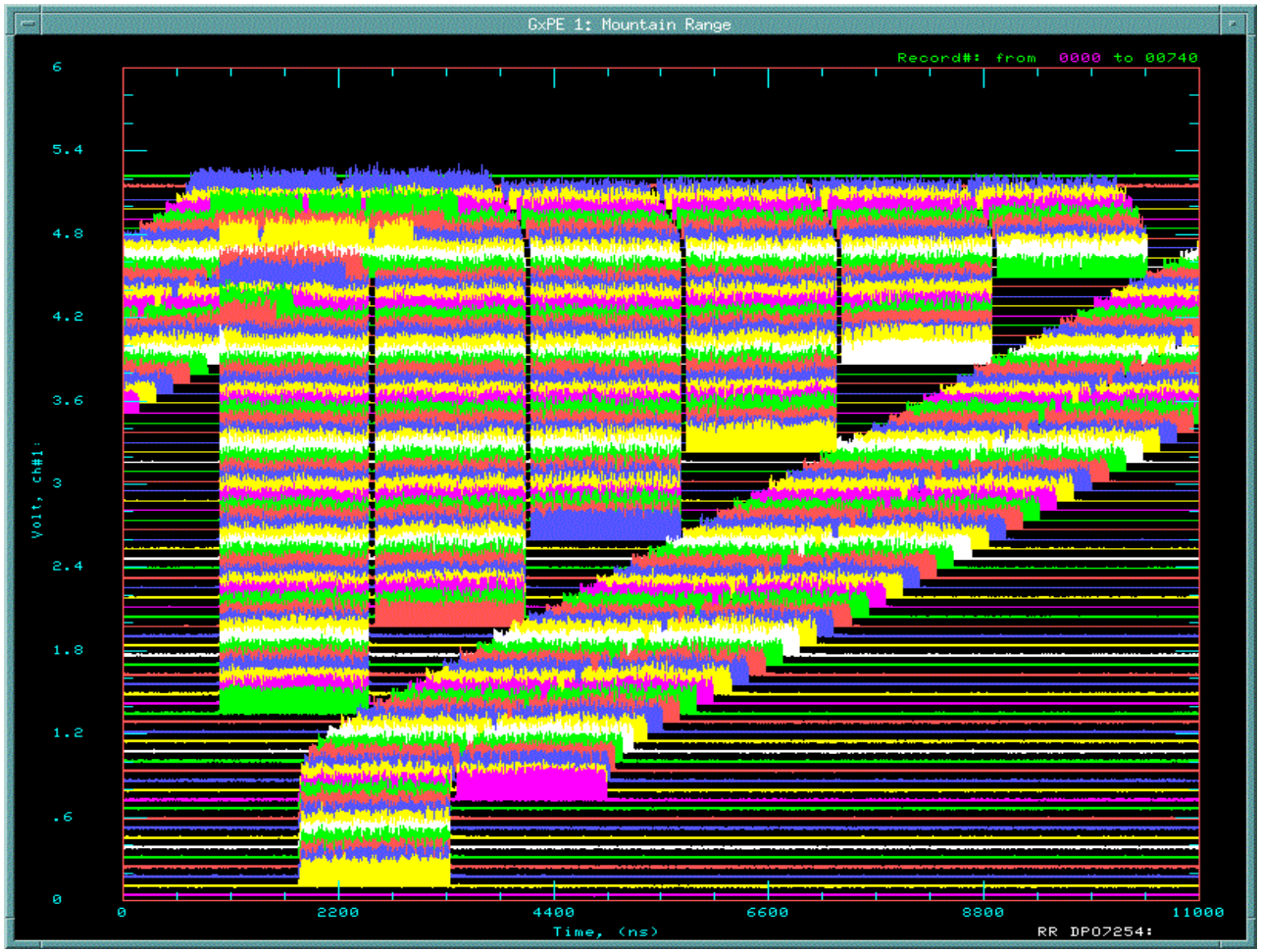
- We have developed a detailed plan to achieve 700-KW beam power to the NuMI target.
  - Includes requirements for both the MI/RR and the Proton Source.
  - Active document; updated each time we achieve or fail to achieve a milestone.
- We have already achieved the first 3 milestones and have delivered a record beam power of 521 KW to the NuMI target.
- We see no show stoppers achieving 700-KW to the NuMI target in FY16.
  - Continuing to address RR aperture problems and improving losses.
  - We are developing a Recycler collimation plan in order to be able to run reliably at 700KW.

EXTRA SLIDES

2+6 mountain Range

2 Double and 4 Single batches

Time



Position in RR Ring

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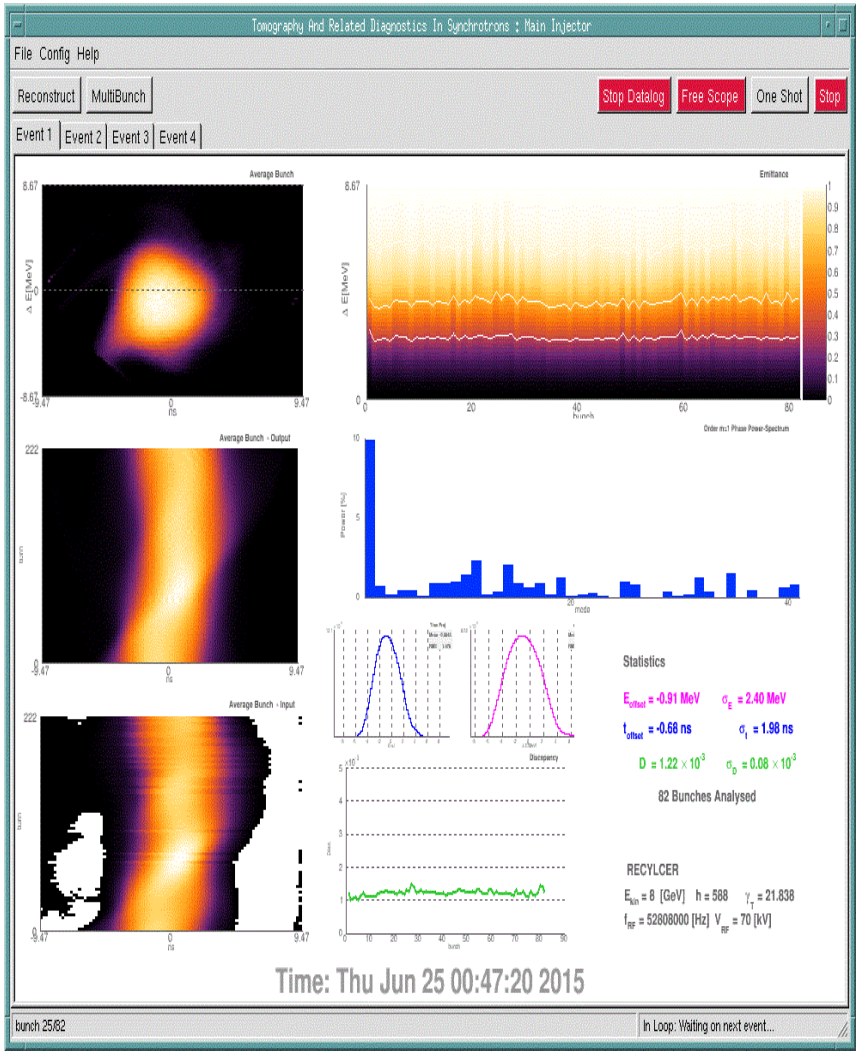
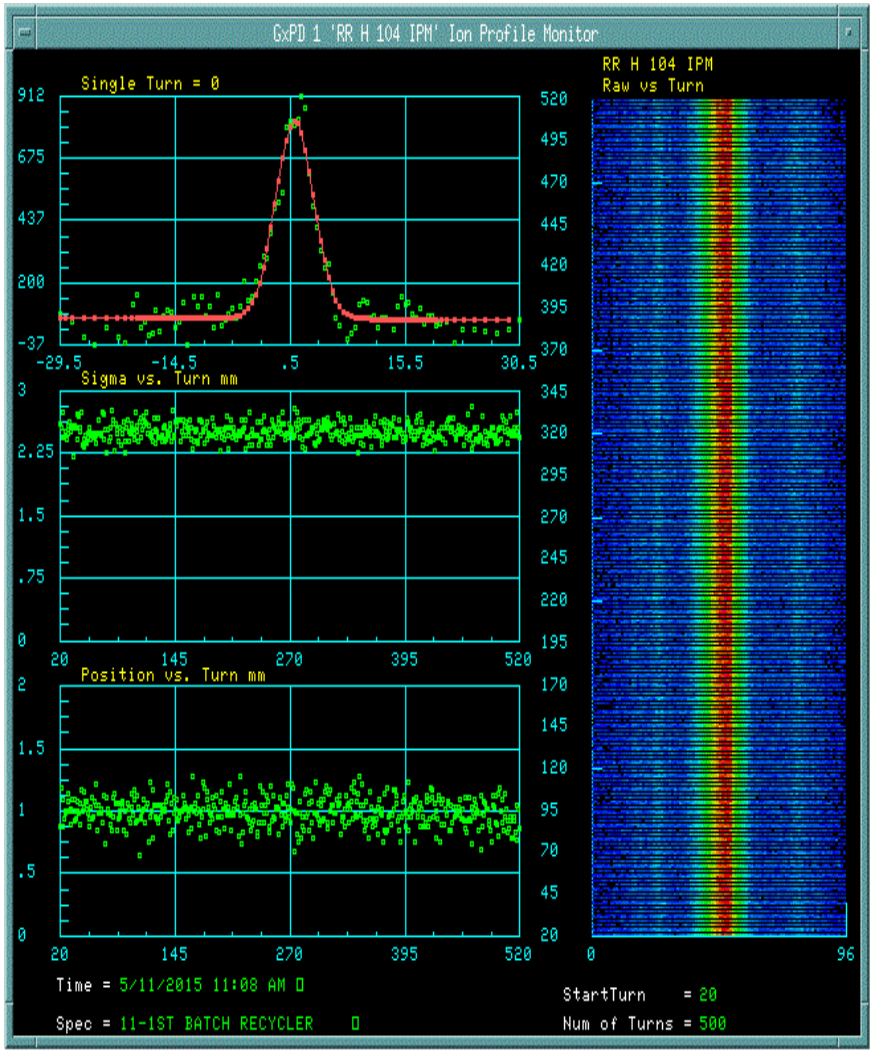
Booster emittances





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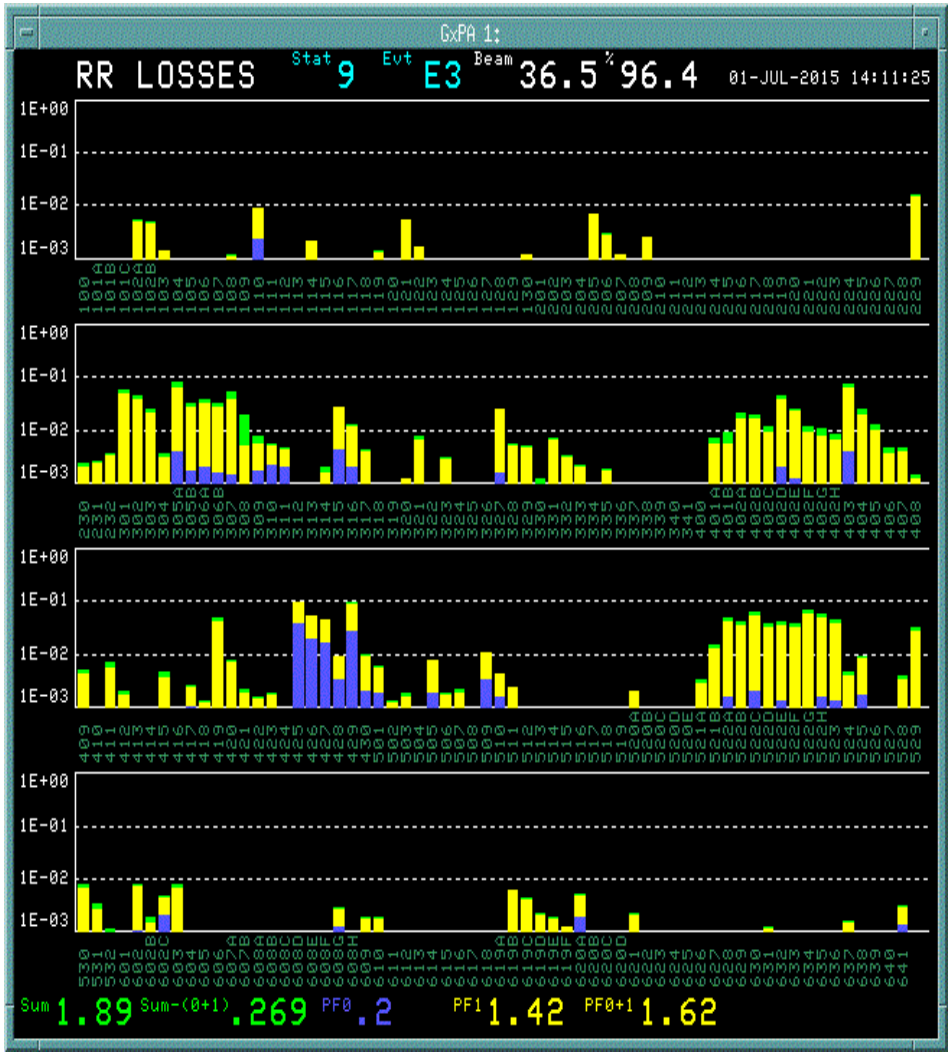
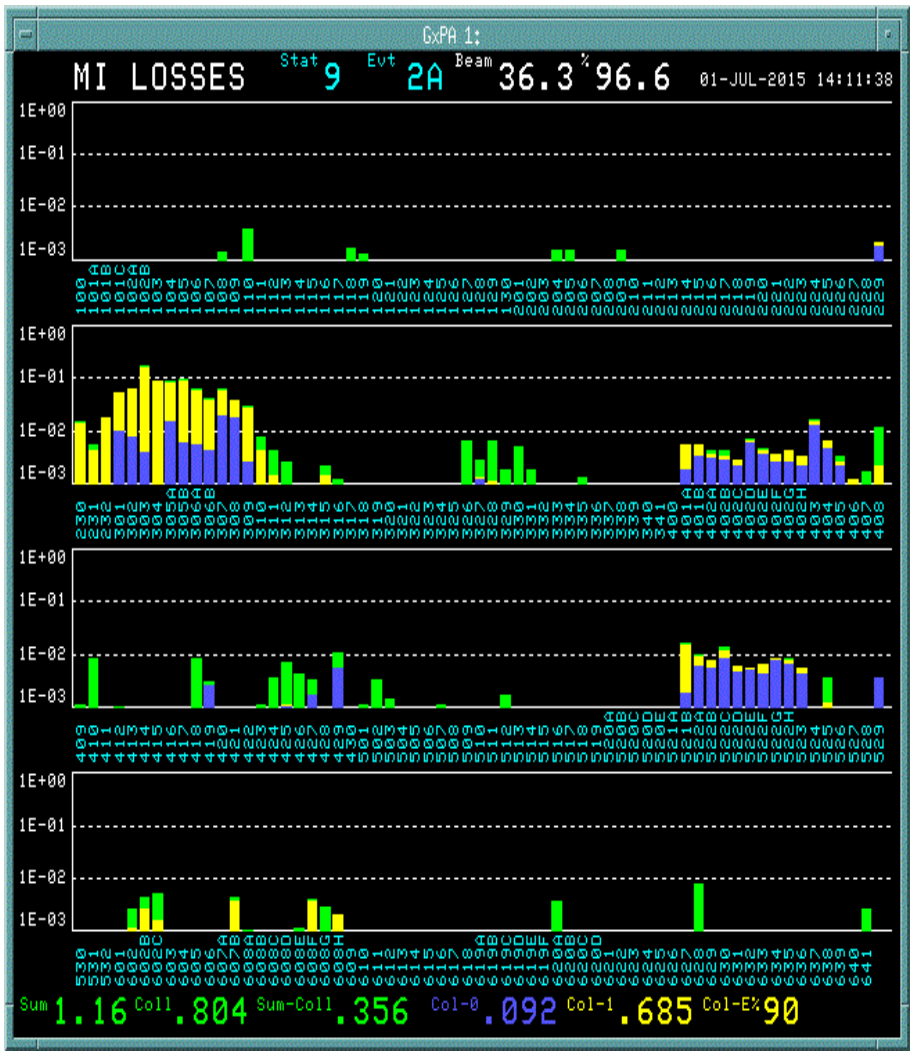
4+6 Losses





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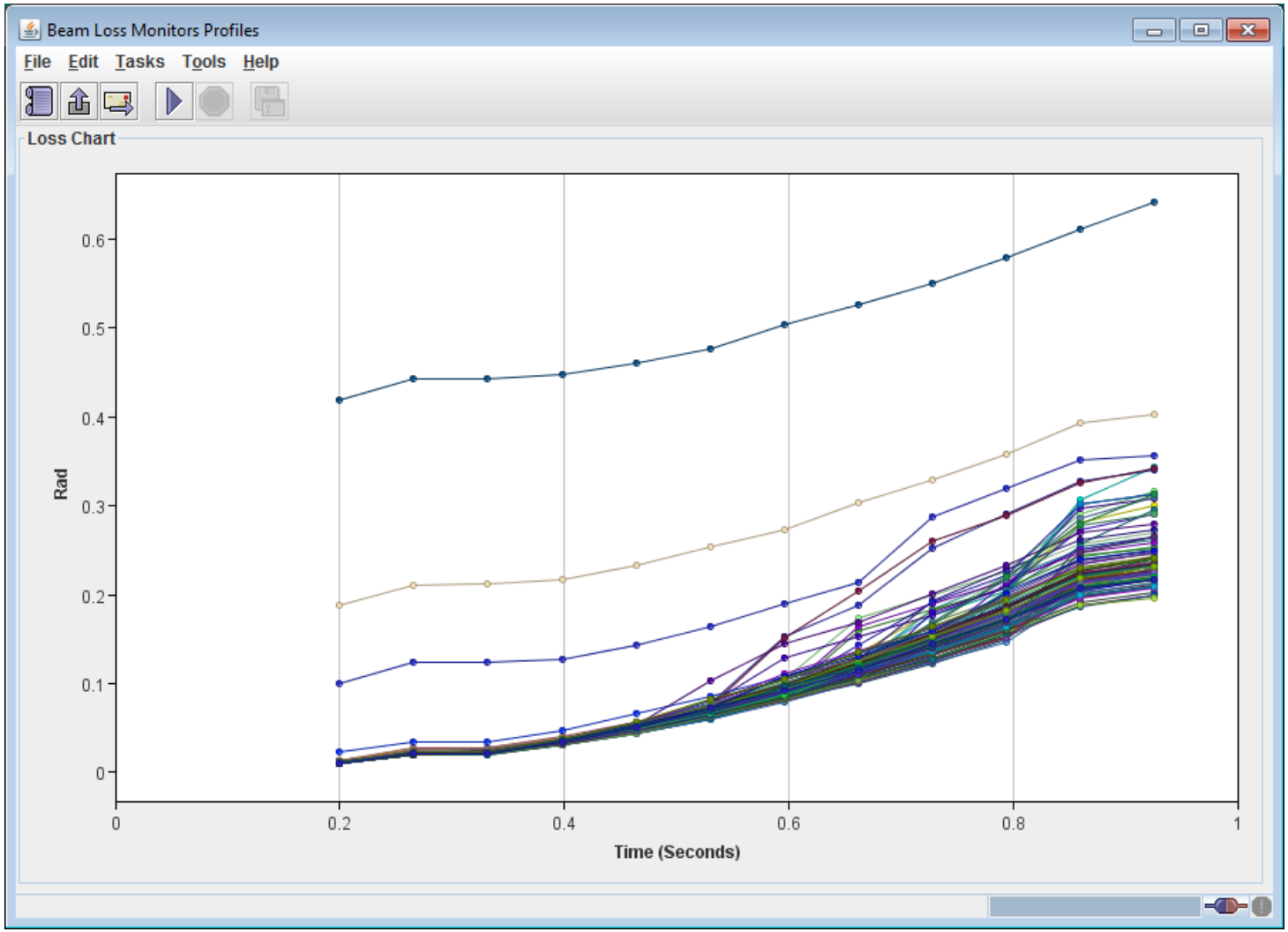
Recycler losses vs injection number (2+6)



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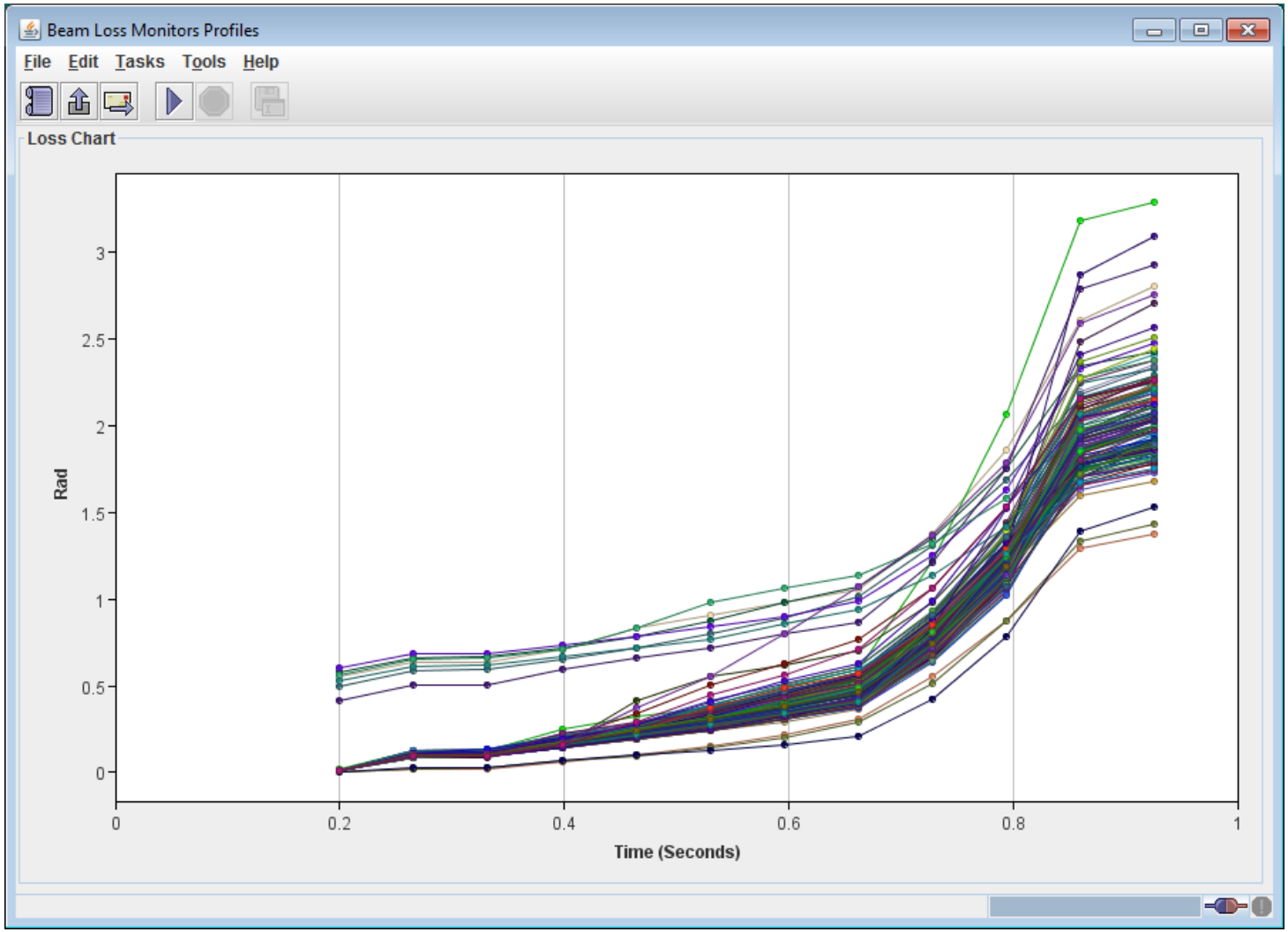
Recycler losses vs Injection time (4+6)



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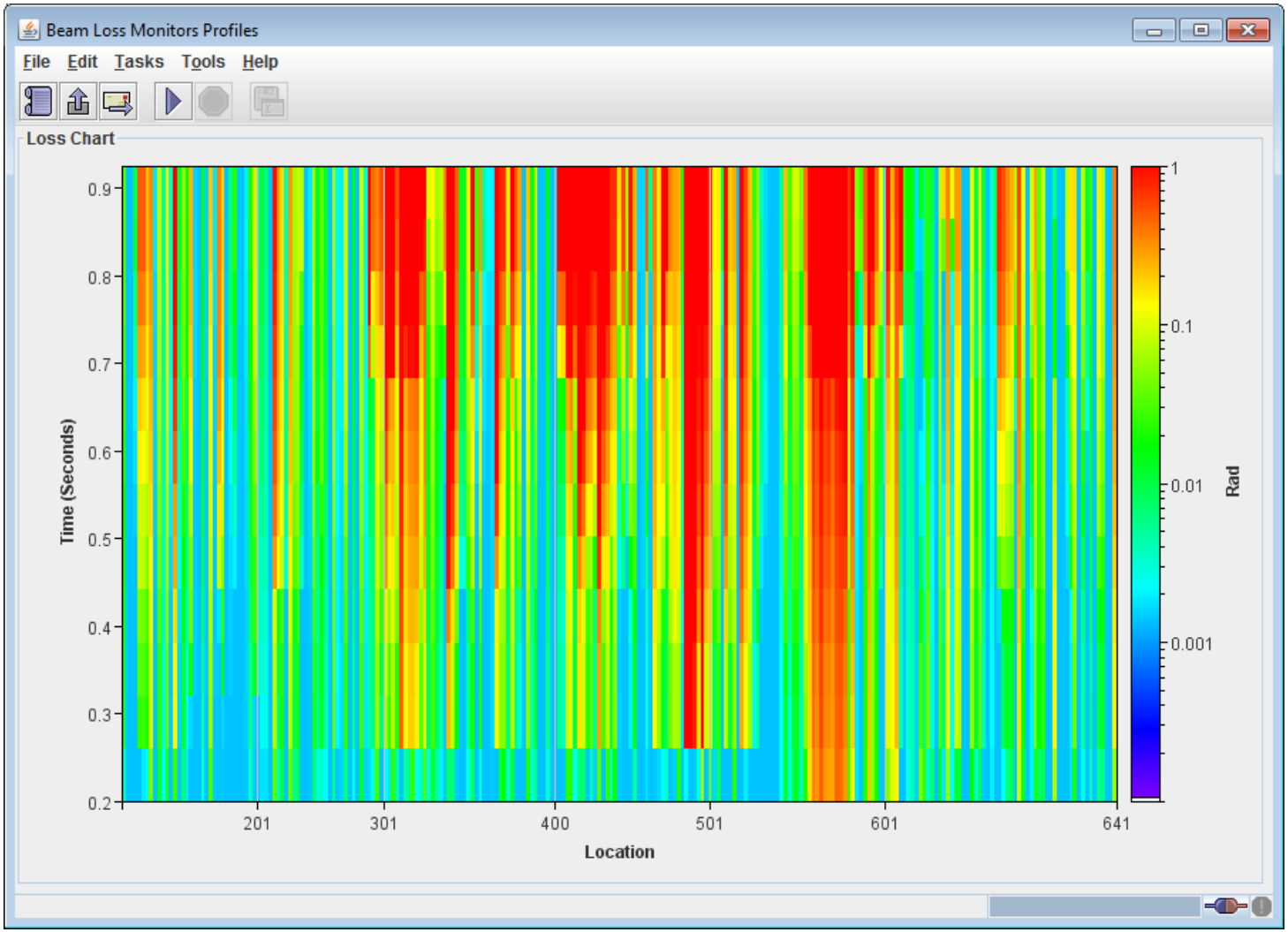
Beam Loss Monitors Profiles
File Edit Tasks Tools Help
Loss Chart
Time (Seconds)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
201
301
400
501
601
641
Location
1
0.1
0.01
0.001
Rad

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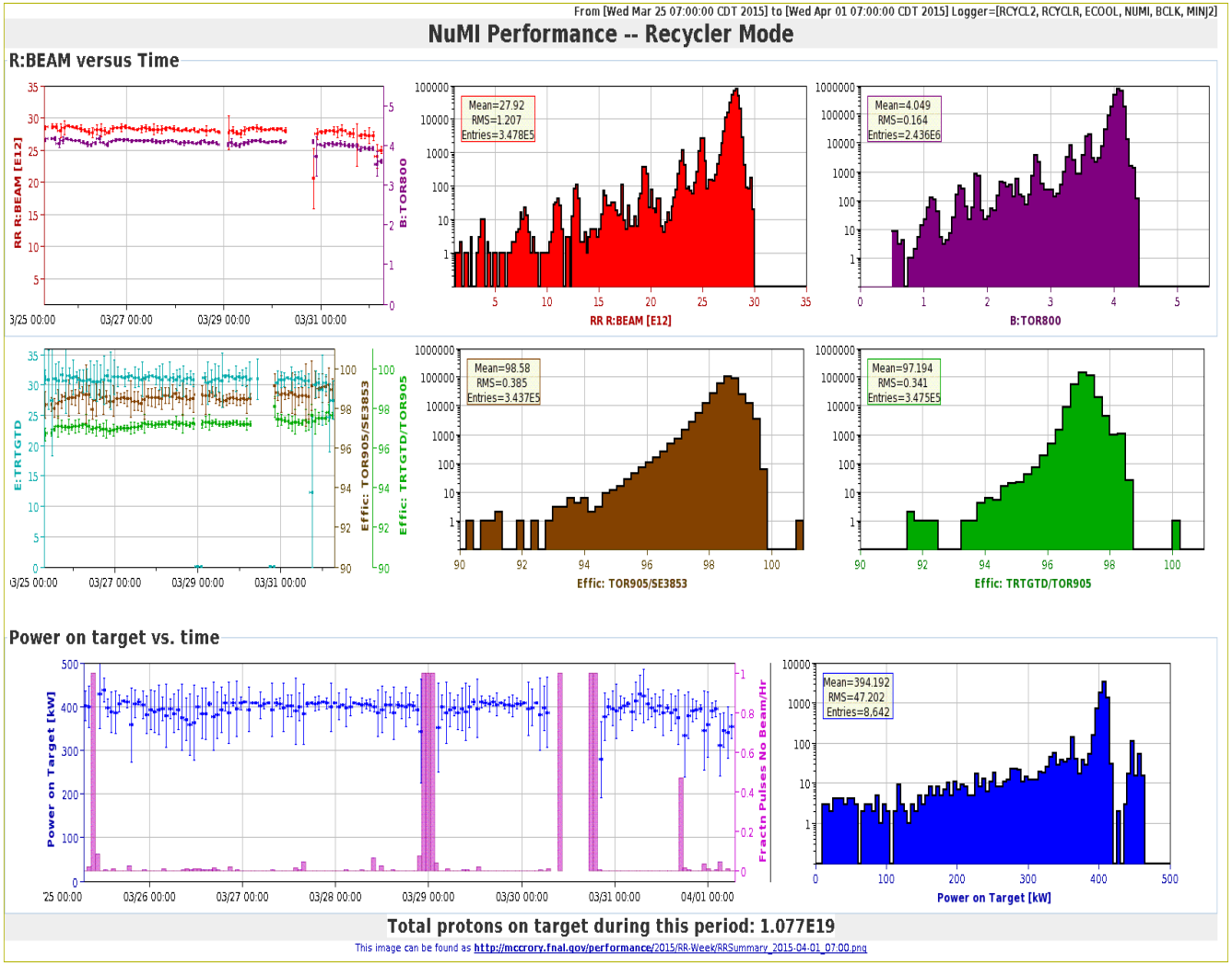
Weekly NuMI performance



RR Beam

RR and MI efficiencies

Beam Power

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RR Collimator Schematic